EVM User's Guide: LM65680-Q1EVM

LM65680-Q1 70V, 8A Buck Regulator Evaluation Module

Description

The LM65680-Q1EVM evaluation module (EVM) is a synchronous, buck, DC/DC regulator that employs synchronous rectification to achieve high conversion efficiency in a small footprint. The EVM operates over a wide input voltage range of 6V to 70V, which offers outsized voltage rating and operating margin to withstand supply-rail voltage transients while providing a regulated output of 5V. The output voltage has better than 1% setpoint accuracy and is adjusted by modifying the feedback resistor values, permitting the user to customize the output voltage as needed.

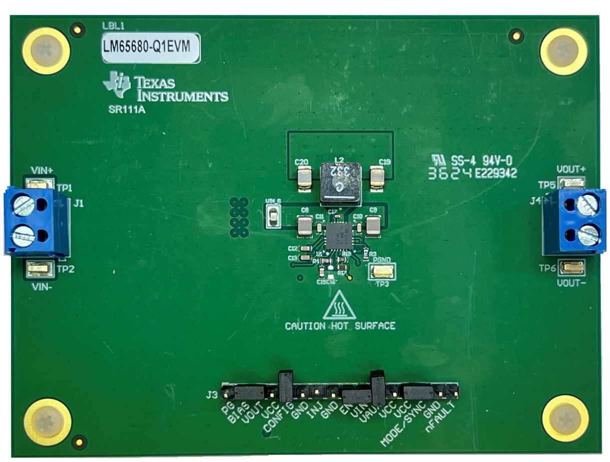
The selected input and output capacitors accommodate the entire range of input voltage. Output voltage configuration must be limited to 5V since output capacitors are rated for 10V for small solution size. For output voltages higher than 5V, careful consideration of higher voltage rated capacitors is recommended.

Features

- Wide input voltage operating range of 6V to 70V
- Adjustable output down to 0.8V
- Switching frequency of 400kHz externally synchronizable up or down by 20%
- Full-load efficiency of 91.7% at $12V_{IN}$, 91.5% at $24V_{IN}$ and 90% at $48V_{IN}$
- 15µA no load operating current at $48V_{IN}$
- Designed for low Electromagnetic Interference (EMI)
  - Dual-random spread spectrum EMI mitigation
  - Meets CISPR 25 Class 5 and UNECE Reg 10 EMI standards
- Peak current-mode control architecture provides fast line and load transient response
  - Integrated slope compensation adaptive with switching frequency
  - Forced pulsed width modulation (FPWM) or pulsed frequency modulation (PFM) operation
  - Optional internal or external loop compensation
- Integrated high-side and low-side power MOSFETs
- Overcurrent protection (OCP) with hiccup mode for sustained overload conditions
- SYNCOUT signal 180° out-of-phase with internal clock
- Power-Good (PG) signal with 100kΩ pullup resistor to VOUT
- Internal 5.3ms soft start (SS)
- Fully assembled, tested, and proven PCB layout

Applications

- Advanced Driver Assistance Systems (ADAS)
- Automotive infotainment and cluster
- Hybrid, electric and powertrain systems



1 Evaluation Module Overview

1.1 Introduction

The LM65680-Q1EVM uses the LM65680-Q1 synchronous buck converter IC with input voltage range up to 70V and output current up to 8A. The default evaluation module (EVM) features an output voltage that is set to 5V adjustable and a switching frequency of 400kHz.

The design supports adjustable input voltage UVLO for application-specific power-up and power-down requirements, external clock synchronization to mitigate beat frequencies in noise-sensitive applications, power good (PG) indicator for sequencing and output voltage monitoring, pin-selectable dual random spread spectrum (DRSS) control for electromagnetic interference (EMI) mitigation, pin selectable MODE control for light-load performance (pulsed frequency modulation - PFM) with AUTO mode or fixed switching frequency with forced pulsed width modulation (FPWM) mode, pin selectable COMP feature for internal or external compensation, and soft start (SS) feature to extend the soft-start time.

The LM65680-Q1 synchronous buck converter used in the EVM has the following features:

- Wide input voltage (wide V_{IN}) range of 3V to 70V
- Dual random spread spectrum (DRSS) modulation for lower EMI
- Wide duty cycle range with low $t_{ON(min)}$ and $t_{OFF(min)}$
- Ultra-low shutdown and no-load standby quiescent currents
- Multiphase capability
- Peak current-mode control loop architecture
- Integrated, high-current MOSFETs
- Cycle-by-cycle overcurrent protection with hiccup

1.2 Kit Contents

- LM65680-Q1EVM Circuit Board
- EVM Disclaimer Read Me
- Prototype EVM Disclaimer Read Me

1.3 Specification

The following figure shows the schematic of an LM65680-Q1 based synchronous buck converter.

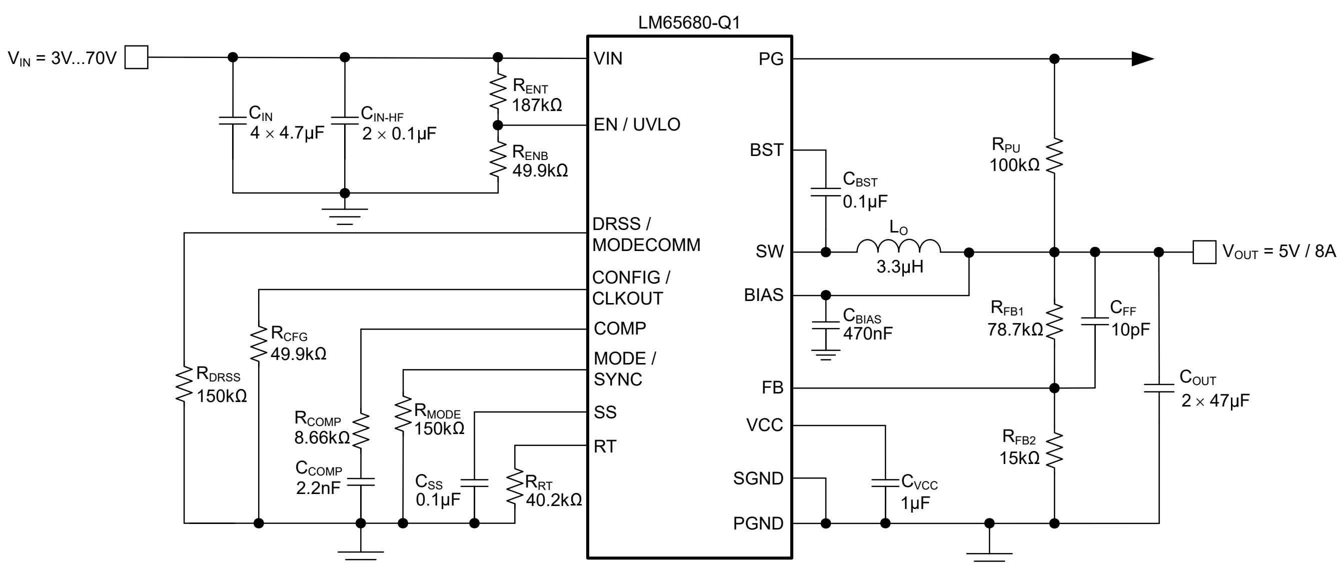


Figure 1-1. LM65680-Q1 Synchronous Buck Regulator Simplified Schematic

1.4 Device Information

With an input operating voltage range from 3V to 70V and rated output current up to 8A, the LM65680-Q1 buck converter provides flexibility, scalability, and optimized solution size for a wide range of applications. The device enables design for high power density and low EMI solutions. Available EMI mitigation includes dual random spread spectrum (DRSS) and slew rate (SR) control to reduce peak EMI emissions.

The free-running switching frequency of the EVM is 400kHz and is synchronizable to a higher or lower frequency, if required. VCC and gate drive UVLO protects the regulator at low input voltage conditions, and EN pin supports application-specific power-up and power-down requirements. The LM65680-Q1 is available in a 26-pin VQFN package with 4.5mm × 4.5mm footprint to enable DC/DC devices with high density and low component count. See the *LM65680-Q1 70V, 8A, Automotive Buck Converter Optimized for Low EMI and High Power Density* data sheet for more information.

2 Hardware

2.1 Test Setup and Procedure

2.1.1 EVM Connections

Referencing the EVM connections described in Table 2-1, the recommended test setup to evaluate the LM65680-Q1 is shown in Figure 2-1. Working at an ESD-protected workstation, make sure that any wrist straps, boot straps, or mats are connected and referencing the user to earth ground before handling and applying power to the EVM.

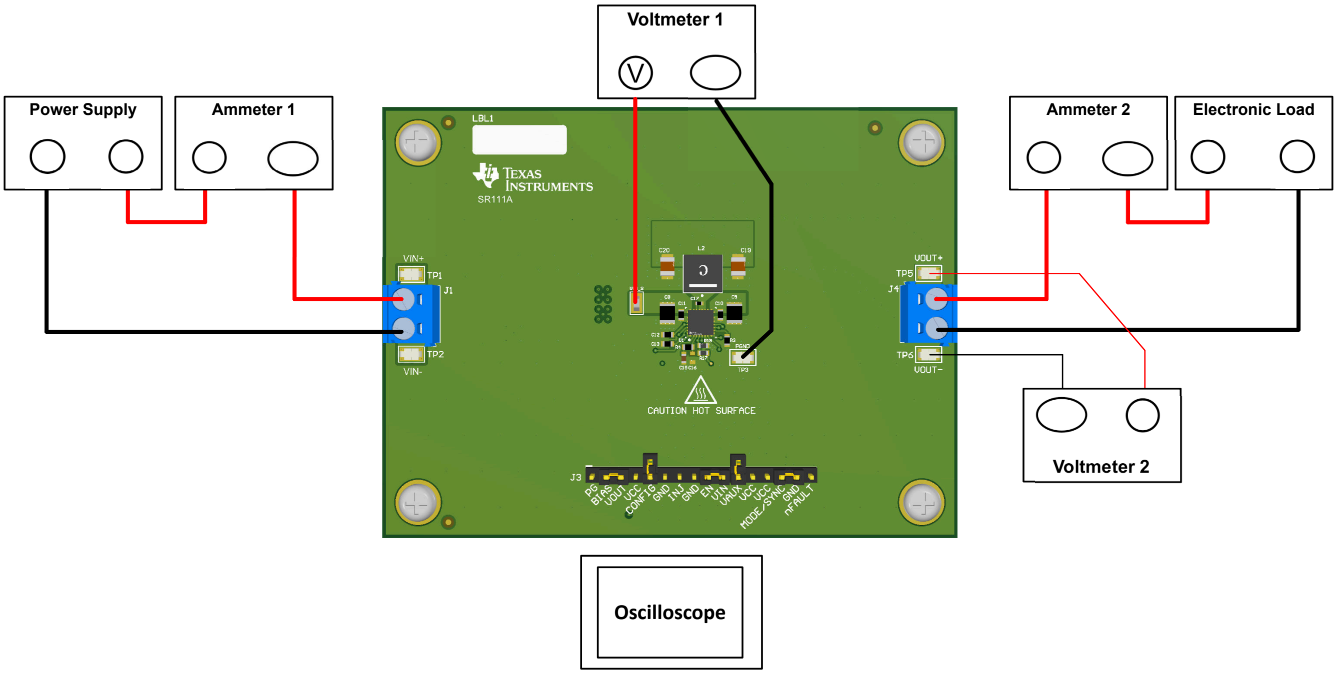


Figure 2-1. EVM Test Setup

Note

Refer to the *LM65680-Q1 70V, 8A, Automotive Buck Converter Optimized for Low EMI and High Power Density* data sheet, LM65680-Q1 Quickstart Calculator, and WEBENCH® Power Designer for additional guidance pertaining to component selection and converter operation.

Table 2-1. EVM Power Connections

LABEL	DESCRIPTION
VIN+	Positive input power connection
VIN–	Negative input power connection
VOUT+	Positive output power connection
VOUT–	Negative output power connection

Table 2-2. EVM Signal Connections

LABEL	DESCRIPTION
PG	Power-Good indicator
BIAS	Input to internal voltage regulator. Connect to VOUT or optional external bias supply for higher efficiency
VOUT	Output voltage
VCC	Internal regulator output. Do not connect this pin to any external loads.
CONFIG	Loop compensation selection. Connect CONFIG to VCC for internal compensation. Floating the CONFIG pin or connecting CONFIG to GND for external compensation.
GND	GND connection
INJ	50Ω injection point for loop response
GND	GND connection
EN	ENABLE input – tie to GND to disable the device
VIN	Input voltage
VAUX	Requires functional safety IC variant. Auxiliary pull-up voltage for nFault. Connect to VIN, VCC, or optional external bias supply.
VCC	Internal regulator output. Do not connect this pin to any external loads.
VCC	Internal regulator output. Do not connect this pin to any external loads.
MODE/SYNC	PFM / FPWM selection and synchronization input. Connect MODE/SYNC to GND for AUTO mode or to VCC for FPWM mode. The MODE/SYNC pin can also be driven by an external synchronization clock signal to operate in FPWM mode.
GND	GND connection
nFAULT	Requires functional safety IC variant. Test point used to monitor if any faults has occurred in the regulator or the system. nFAULT is an active low fault signal.

2.1.2 Test Equipment

Voltage Source: The input voltage source V_{IN} must be an 80V variable DC source capable of supplying 8A.

Multimeters:

- **Voltmeter 1:** Measure the input voltage at VIN_S to PGND test point.
- **Voltmeter 2:** Measure the output voltage at VOUT+ (TP5) to VOUT– (TP6).
- **Ammeter 1:** Measure the input current. Set the ammeter to 1-second aperture time.
- **Ammeter 2:** Measure the output current. Set the ammeter to 1-second aperture time.

Electronic Load: The load must be an electronic constant-resistance (CR) or constant-current (CC) mode capable of $0A_{DC}$ to $15A_{DC}$. For a no-load input current measurement, disconnect the electronic load as the load can draw a small residual current.

Oscilloscope: With the scope set to 20MHz bandwidth and AC coupling, measure the output voltage ripple directly across an output capacitor with a short ground lead normally provided with the scope probe. Place the oscilloscope probe tip on the positive terminal of the output capacitor, holding the ground barrel of the probe through the ground lead to the negative terminal of the capacitor. TI does not recommend using a long-leaded ground connection because this can induce additional noise given a large ground loop. To measure other waveforms, adjust the oscilloscope as needed.

Safety: Always use caution when touching any circuits that can be live or energized.

2.1.3 Recommended Test Setup

2.1.3.1 Input Connections

- Prior to connecting the DC input source, set the current limit of the input supply to 0.1A maximum. Make sure the input source is initially set to 0V and connected to the VIN+ and VIN– connection points as shown in Figure 2-1.
- Connect voltmeter 1 at VIN_S and PGND (TP3) connection points to measure the input voltage.
- Connect ammeter 1 to measure the input current and set the ammeter to at least a 0.1 second aperture time.

2.1.3.2 Output Connections

- Connect an electronic load to VOUT+ and VOUT– connections as shown in Figure 2-1. Set the load to constant-resistance mode or constant-current mode at 0A before applying input voltage.
- Connect voltmeter 2 at VOUT+ (TP5) and VOUT– (TP6) sense points to measure the output voltage.
- Connect ammeter 2 to measure the output current.

2.1.4 Test Procedure

2.1.4.1 Line, Load Regulation, and Efficiency

- Set up the EVM as described in *EVM Connections*.
- Set load to constant resistance or constant current mode to sink 0A.
- Increase the input source voltage from 0V to 70V; use voltmeter 1 to measure the input voltage.
- Increase the current limit of the input supply to 8A.
- Use voltmeter 2 to measure the output voltage, V_{OUT}, and vary the load current from 0A to 8A DC; V_{OUT} must remain within the load regulation specification.
- Set the load current to 4A (50% rated load) and vary the input source voltage from 6V to 70V; V_{OUT} must remain within the line regulation specification.
- Set the load current to 8A (100% rated load) and measure the efficiency at typical input voltages (12V, 24V, 36V, 48V and 65V).
- Decrease the load to 0A. Decrease the input source voltage to 0V.

CAUTION

Extended operation at high output current can raise component and EVM board temperatures above 55°C. To avoid risk of a burn injury, do not touch the components and the EVM board until cooled sufficiently after disconnecting power.

3 Implementation Results

3.1 Performance Data and Results

The typical performance curves for the LM65680-Q1EVM are shown in Figure 3-1 through Figure 3-15. Because actual performance data can be affected by measurement techniques and environmental variables, these curves are presented for reference and can differ from actual field measurements.

3.1.1 EVM Characteristics

The electrical characteristics for LM65680-Q1EVM are shown in Table 3-1.

Table 3-1. Electrical Performance Characteristics of EVM

Parameter	Test Conditions		MIN	TYP	MAX	Unit
INPUT CHARACTERISTICS						
Input voltage range, V_{IN}	Operating		8	24	70	V
Input current, no load, I_{IN-NL}	I_{OUT} = 0A, MODE/SYNC pin tied to GND	V_{IN} = 12V		29		µA
		V_{IN} = 24V		18		µA
		V_{IN} = 48V		15		µA
		V_{IN} = 65V		15.5		µA
Input voltage turn-on, $V_{IN(ON)}$	Adjusted using EN divide resistors			5.81		V
Input voltage turn-off, $V_{IN(OFF)}$	Adjusted using EN divide resistors			4.73		V
Input voltage hysteresis, $V_{IN(HYS)}$	Adjusted using EN divide resistors			1.08		V
Input current, shutdown, I_{IN-OFF}	V_{EN} = 0V,	V_{IN} = 48V, with 187kΩ and 49.9kΩ EN divider		357		µA
OUTPUT CHARACTERISTICS						
Output voltage, V_{OUT} (1)			4.95	5	5.05	V
Output current, I_{OUT}	V_{IN} = 8V to 65V, Airflow = 100 LFM (2)		0		8	A
Output voltage regulation, ΔV_{OUT}	Load regulation	I_{OUT} = 0A to 8A		0.1%		
	Line regulation	V_{IN} = 8V to 65V		1%		
Output voltage ripple, V_{OUT-AC}	V_{IN} = 48V, I_{OUT} = 8A			35		mVrms
Output overcurrent protection, I_{OCP}	V_{IN} = 48V			8.5		A
Soft-start time, t_{SS}				5.3		ms
SYSTEM CHARACTERISTICS						
Switching frequency, F_{SW-nom}	V_{IN} = 48V			400		kHz
PFM Light-load efficiency, η_{LIGHT} (1)	I_{OUT} = 1A	V_{IN} = 12V		94.3%		
		V_{IN} = 24V		90.9%		
		V_{IN} = 48V		85.3%		
		V_{IN} = 65V		79.7%		
Half-load efficiency, η_{HALF}	I_{OUT} = 4A	V_{IN} = 12V		95.2%		
		V_{IN} = 24V		94%		
		V_{IN} = 48V		91.6%		
		V_{IN} = 65V		89.7%		
Full load efficiency, η_{FULL}	I_{OUT} = 8A	V_{IN} = 12V		91.7		
		V_{IN} = 24V		91.5%		
		V_{IN} = 48V		90%		
		V_{IN} = 65V		88.8%		
LM65680-Q1 junction temperature, T_J			–40		150	°C

(1) The default output voltage of this EVM is 5V. Efficiency and other performance metrics can change based on operating input voltage, load currents, externally-connected output capacitors, and other parameters.
(2) The recommended airflow when operating at input voltages greater than 65V is 100 LFM.

3.1.2 Conversion Efficiency

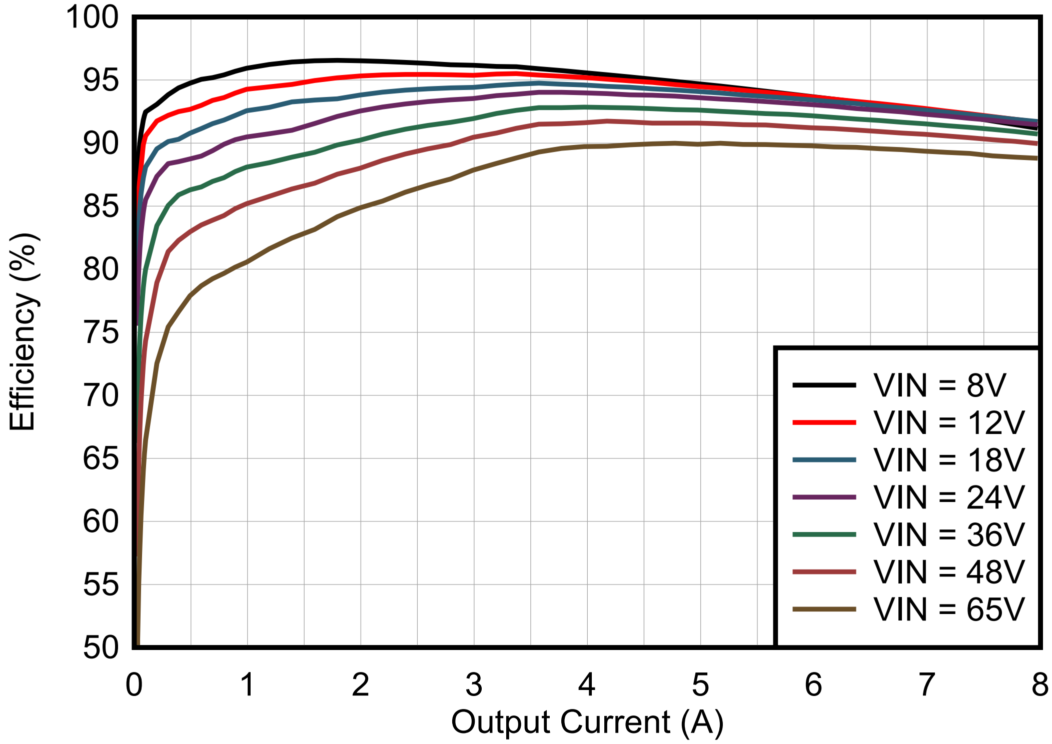


Figure 3-1. Efficiency, V_{IN} = V_{EN} = 8V to 65V, V_{OUT} = 5V, PFM Mode, Linear Scale

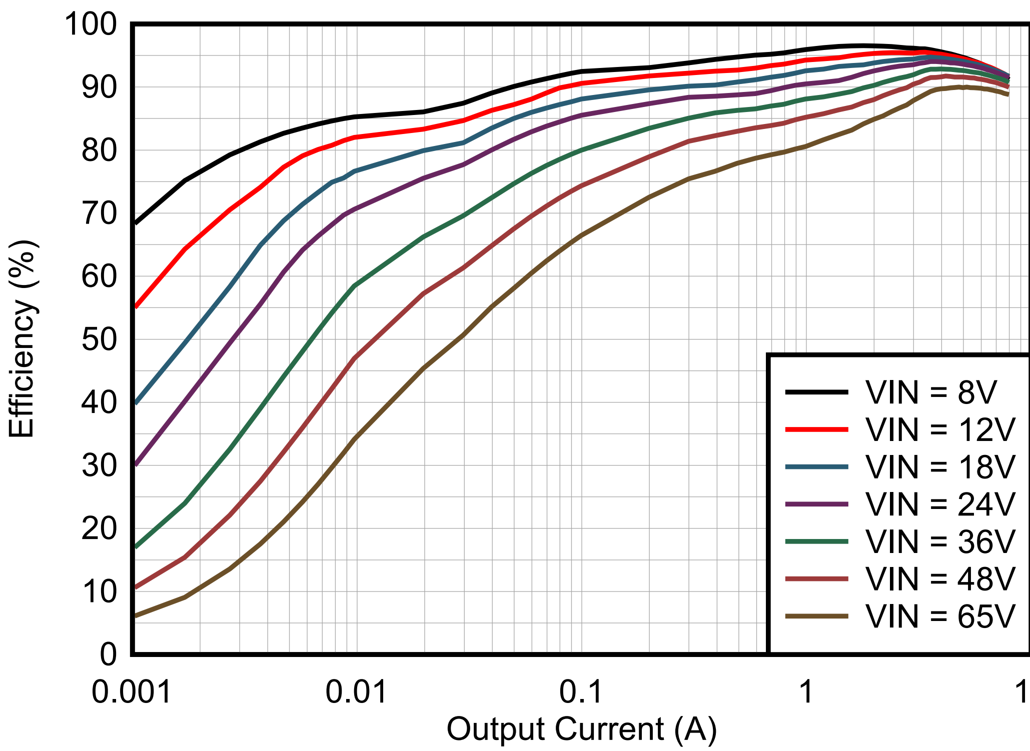


Figure 3-2. Efficiency, V_{IN} = V_{EN} = 8V to 65V, V_{OUT} = 5V, PFM Mode, Logarithmic Scale

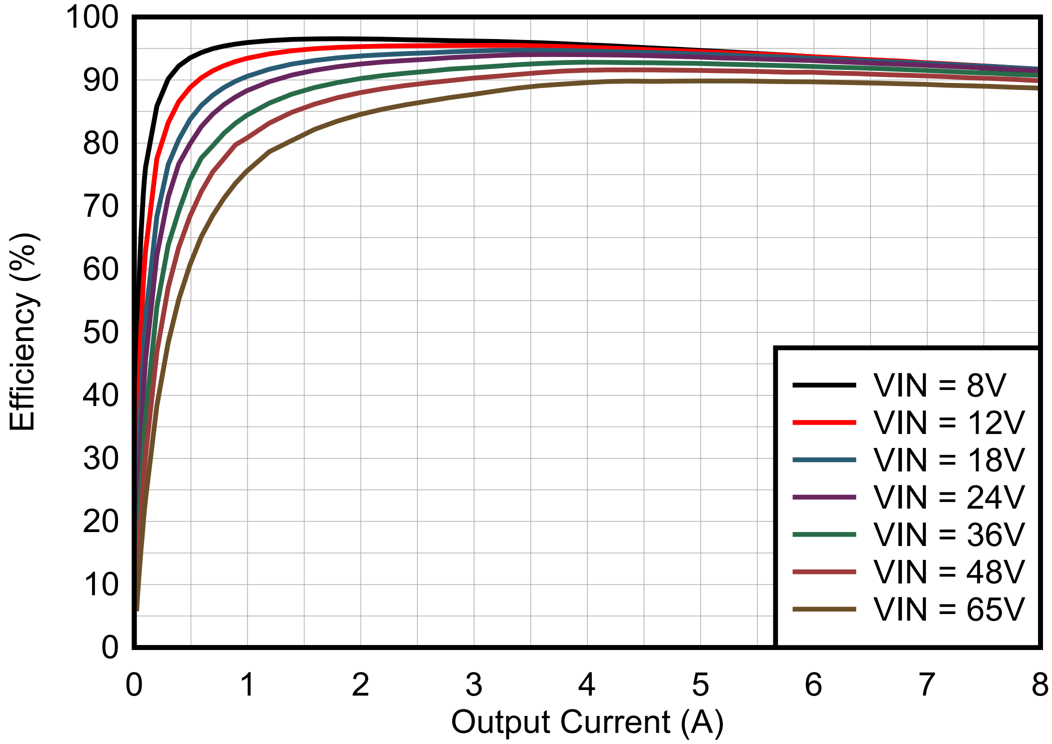


Figure 3-3. Efficiency, V_{IN} = V_{EN} = 8V to 65V, V_{OUT} = 5V, FPWM Mode, Linear Scale

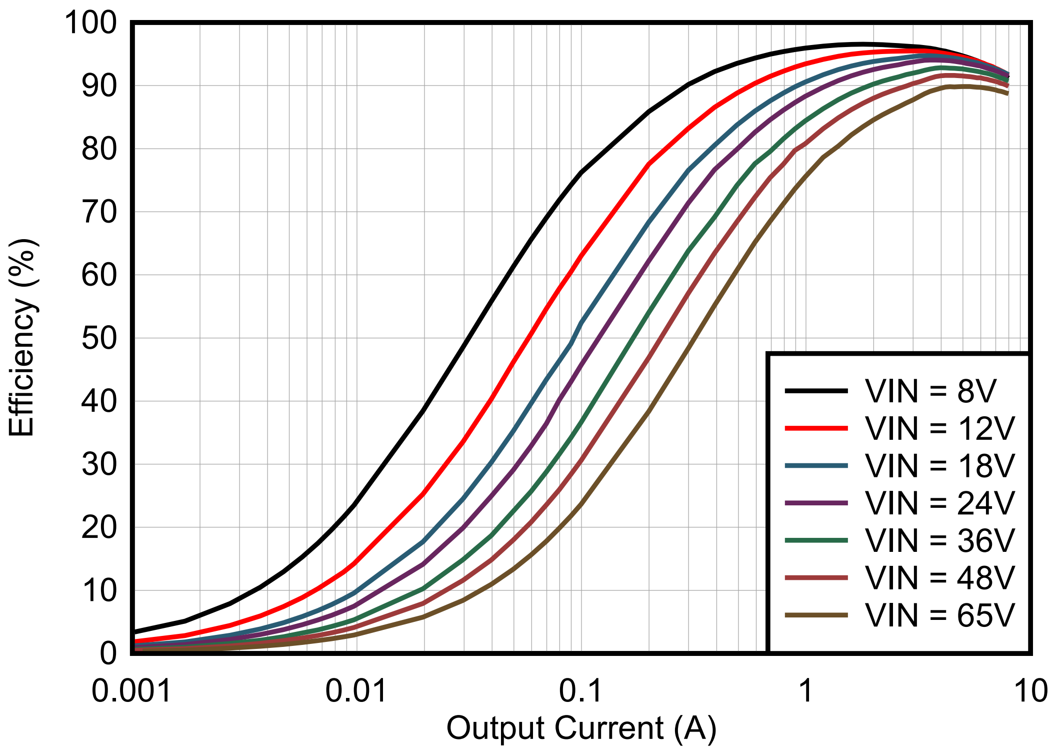


Figure 3-4. Efficiency, V_{IN} = V_{EN} = 8V to 65V, V_{OUT} = 5V, FPWM Mode, Logarithmic Scale

3.1.3 Operating Waveforms

3.1.3.1 Switching

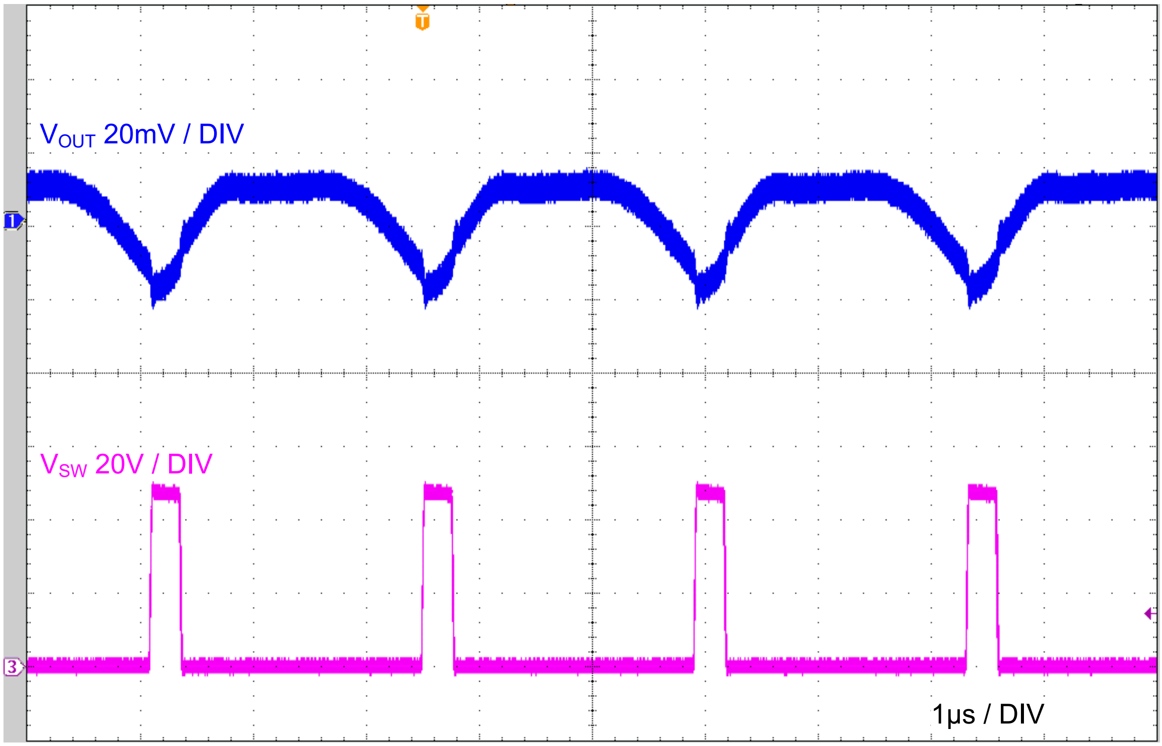


Figure 3-5. Steady State Operation, V_{IN} = 48V, V_{OUT} = 5V, I_{OUT} = 8A, F_{SW} = 400kHz

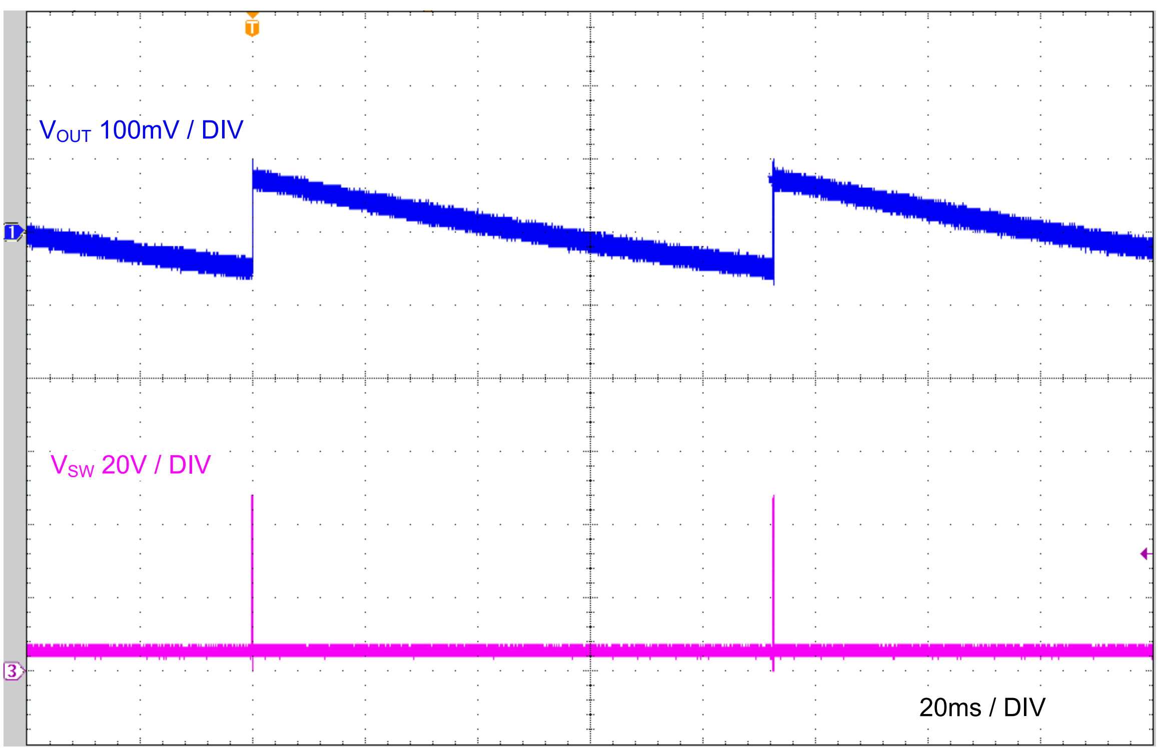


Figure 3-6. Steady State Operation in PFM Mode, V_{IN} = 48V, V_{OUT} = 5V, I_{OUT} = No Load

3.1.3.2 Load Transient Response

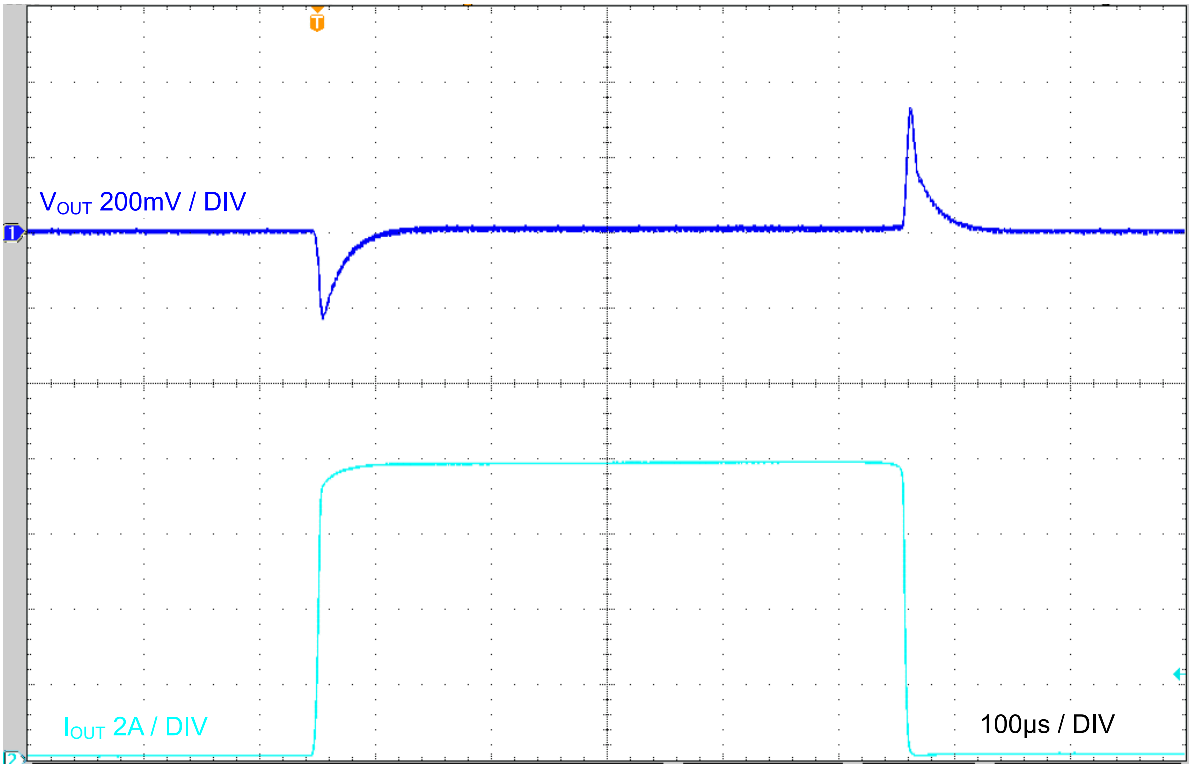


Figure 3-7. Load Transient Response, V_{IN} = 48V, V_{OUT} = 5V, F_{SW} = 400kHz, FPWM, 0A to 8A at 1A/µs

3.1.3.3 Short-Circuit Recovery

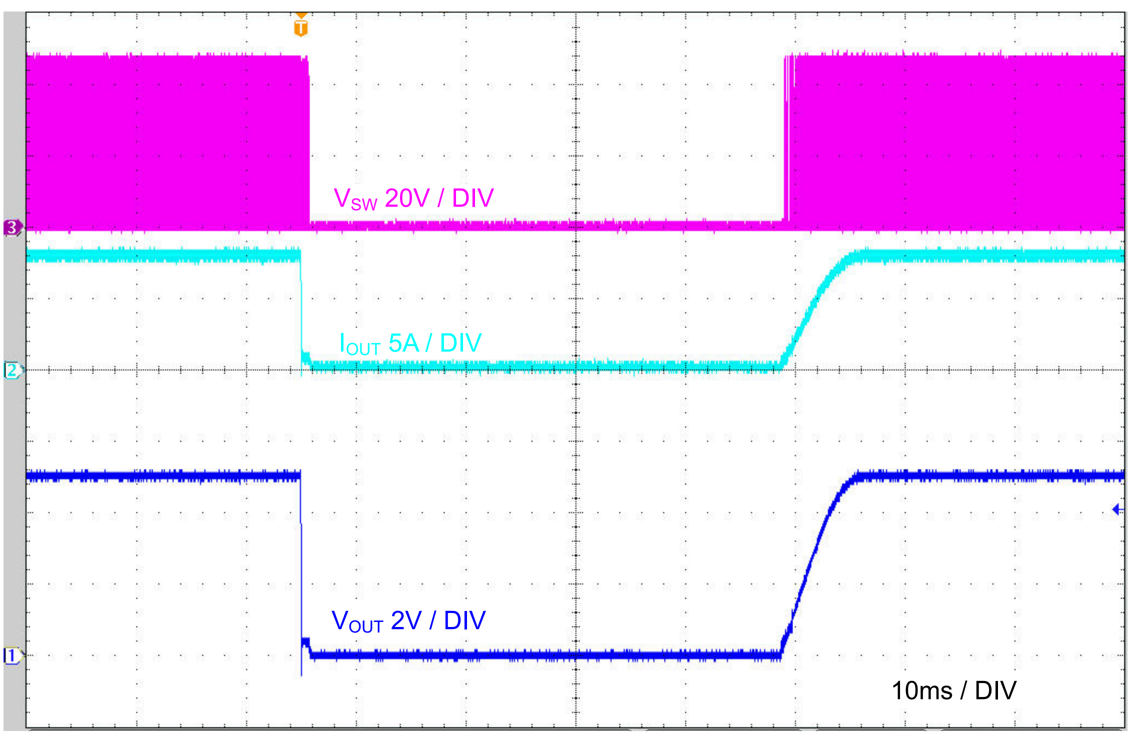


Figure 3-8. Short-Circuit Recovery V_{IN} = 48V, V_{OUT} = 5V, I_{OUT} = 8A, F_{SW} = 400kHz, FPWM

3.1.3.4 Start-Up and Shutdown With EN

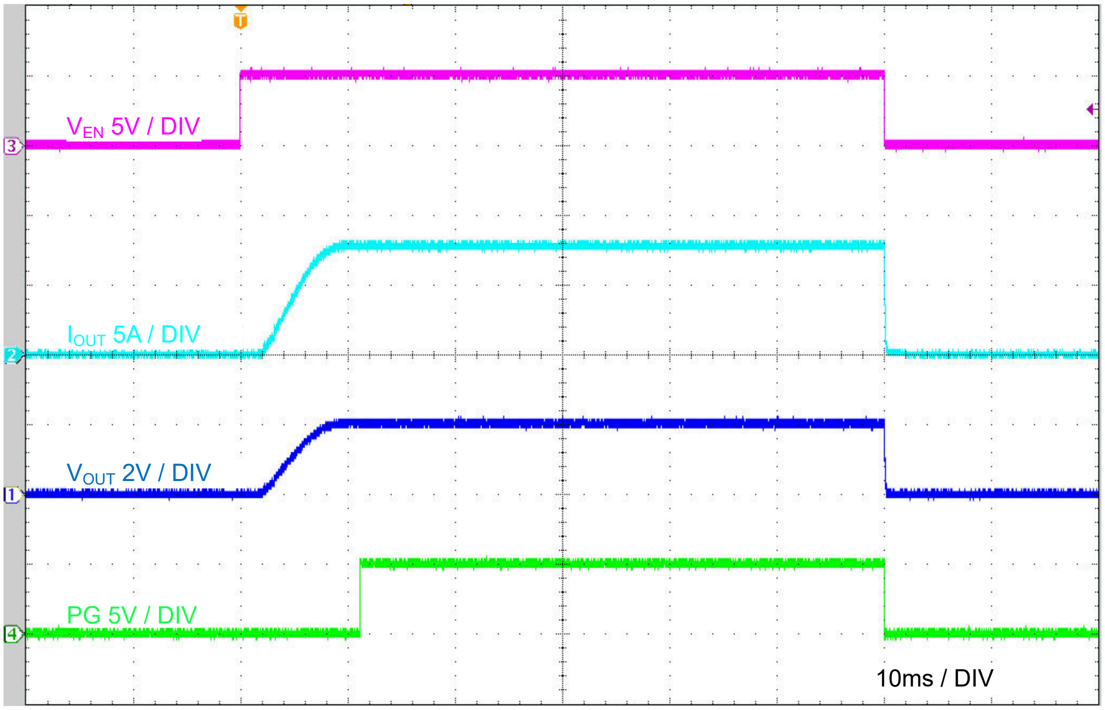


Figure 3-9. EN ON and OFF, V_{IN} = 48V, V_{OUT} = 5V, I_{OUT} = 8A Resistive Load, F_{SW} = 400kHz, FPWM

3.1.3.5 Start-Up With VIN

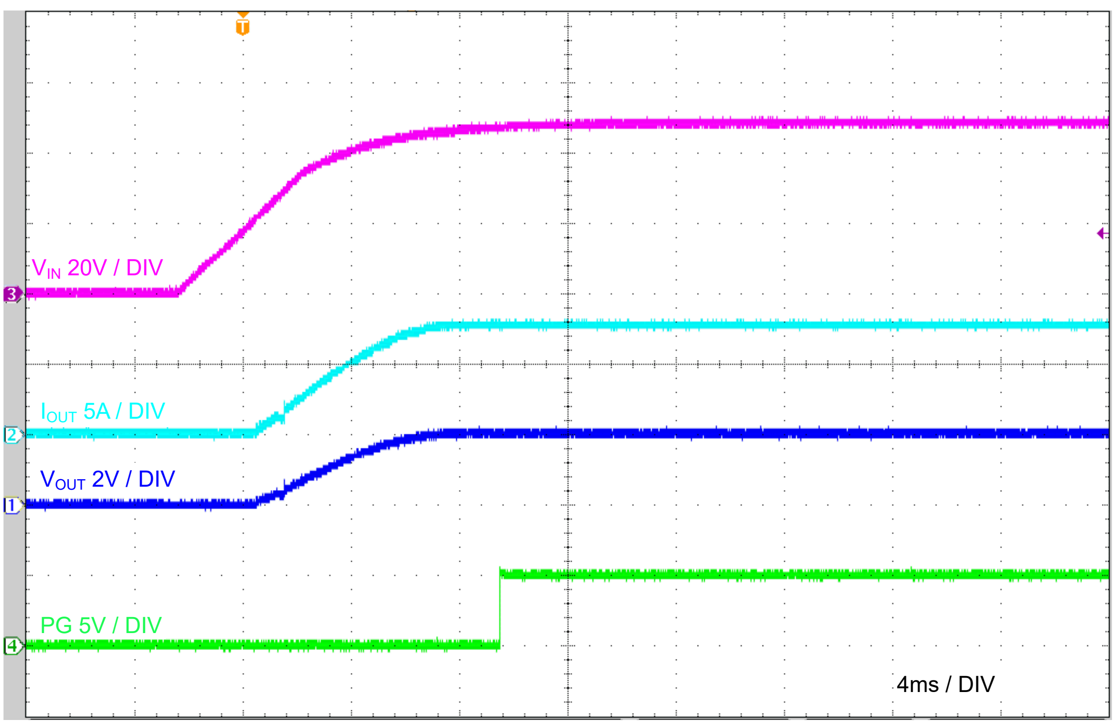


Figure 3-10. Start-Up, V_{IN} = 48V, V_{OUT} = 5V, I_{OUT} = 8A Resistive Load, F_{SW} = 400kHz, FPWM

3.1.4 Bode Plot

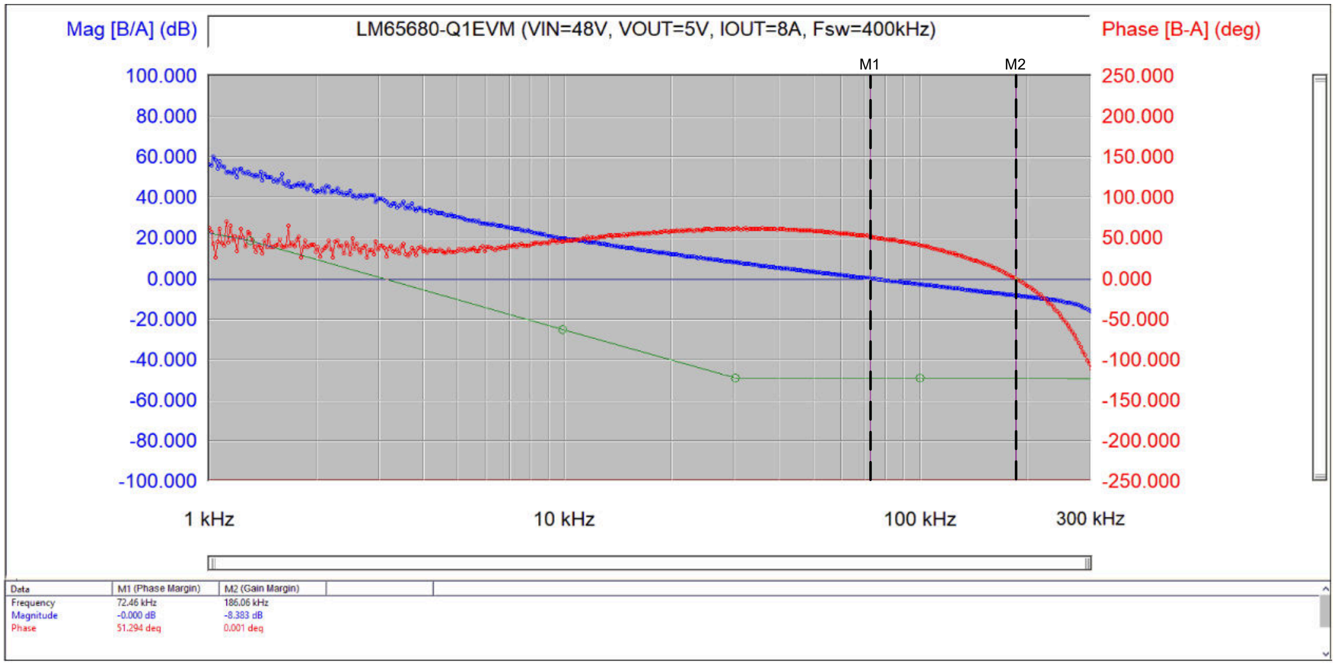


Figure 3-11. Bode Plot, V_{IN} = 48V, V_{OUT} = 5V, I_{OUT} = 8A Resistive Load

3.1.5 CISPR 25 EMI Performance

The EMI performance of the LM65680-Q1 EVM at 24V and 48V input with DRSS EMI mitigation disabled are shown in Figure 3-12 and Figure 3-13. Conducted emissions are measured over a frequency range of 150kHz to 108MHz using a 5µH LISN according to the CISPR 25 specification. CISPR 25 Class 5 peak and average limit lines are denoted in red. The purple and green spectra are measured using peak and average detection, respectively.

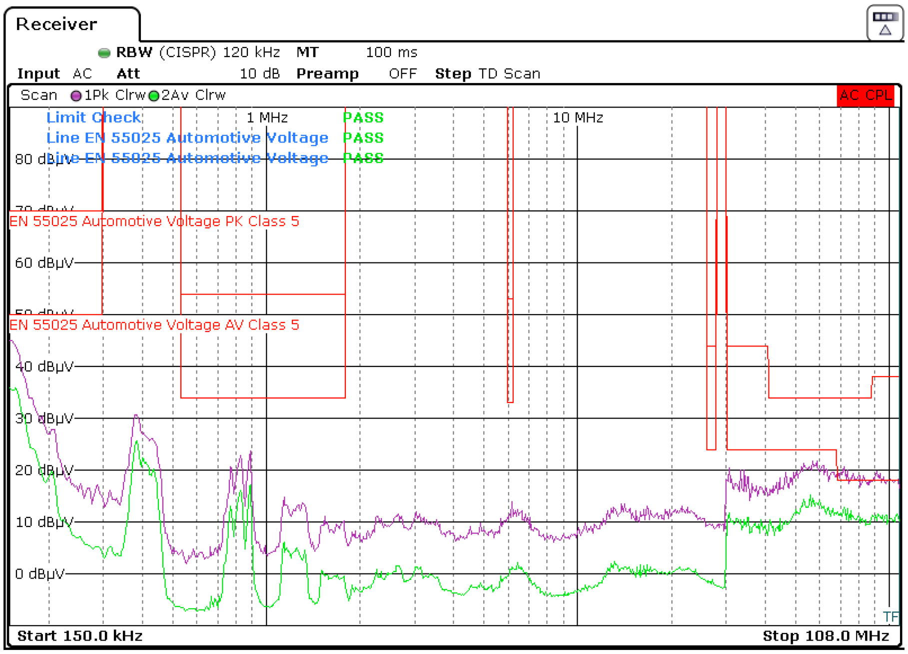


Figure 3-12. CISPR 25 Class 5 Conducted Emissions Plot, 150kHz to 108MHz, V_{IN} = 24V, V_{OUT} = 5V, I_{OUT} = 8A Resistive Load, F_{SW} = 400kHz

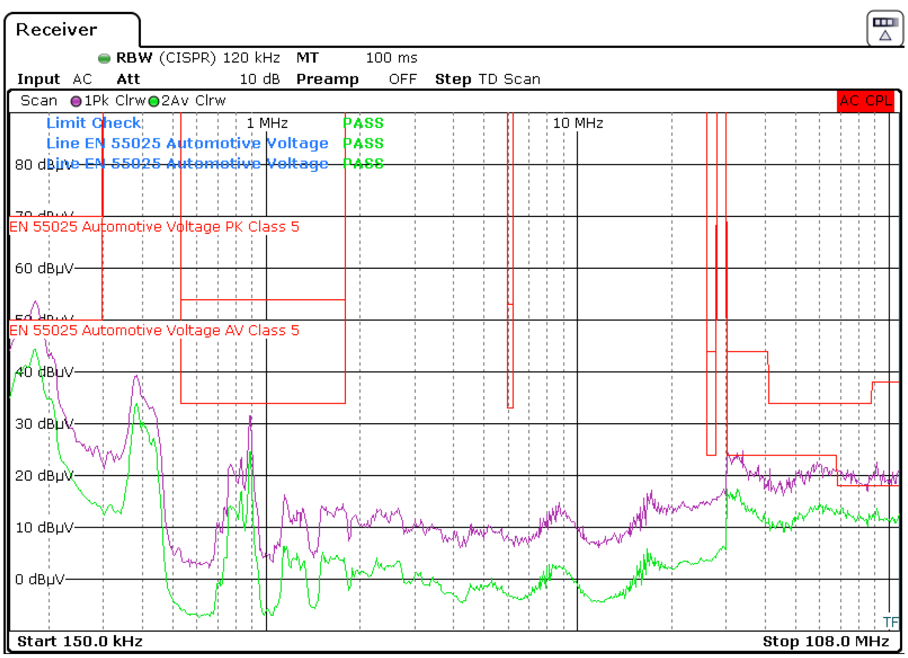


Figure 3-13. CISPR 25 Class 5 Conducted Emissions Plot, 150kHz to 108MHz, V_{IN} = 48V, V_{OUT} = 5V, I_{OUT} = 8A Resistive Load, F_{SW} = 400kHz

3.1.6 Thermal Performance

The thermal performance images are shown in Figure 3-14 and Figure 3-15.

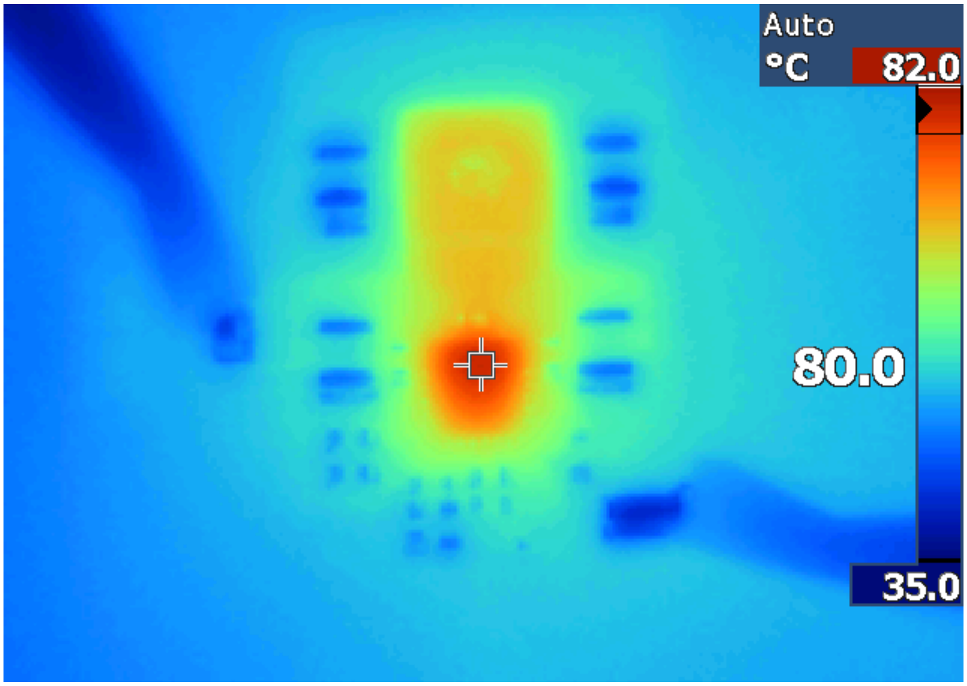


Figure 3-14. Thermal Performance, V_{IN} = 24V, V_{OUT} = 5V, I_{OUT} = 8A, T_{amb} = 25°C, No Airflow

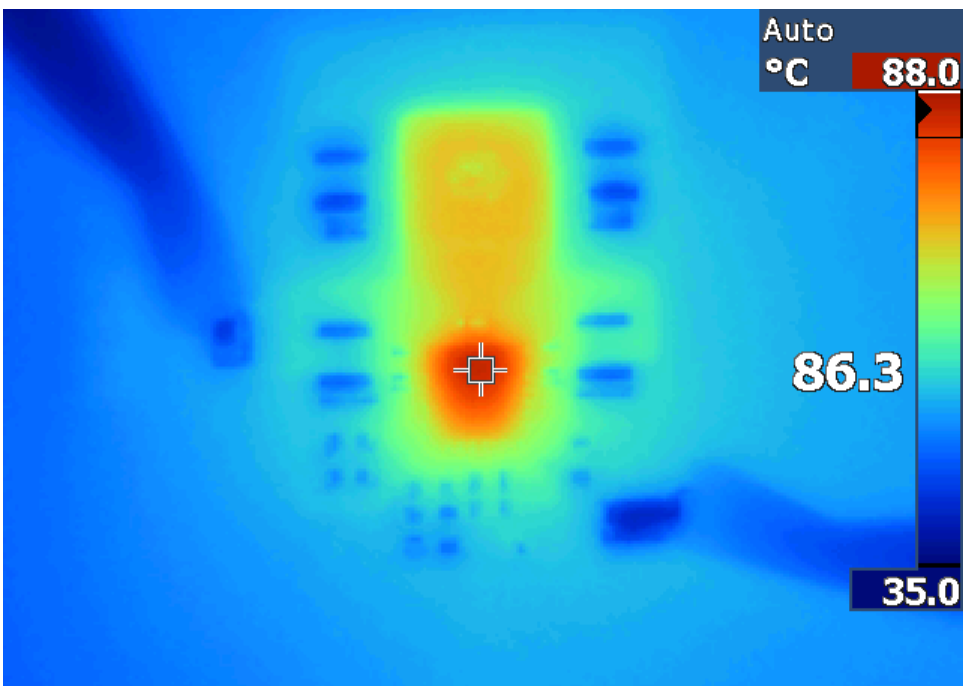


Figure 3-15. Thermal Performance, V_{IN} = 48V, V_{OUT} = 5V, I_{OUT} = 8A, T_{amb} = 25°C, No Airflow

4 Hardware Design Files

4.1 Schematic

The EVM schematic is illustrated in Figure 4-1.

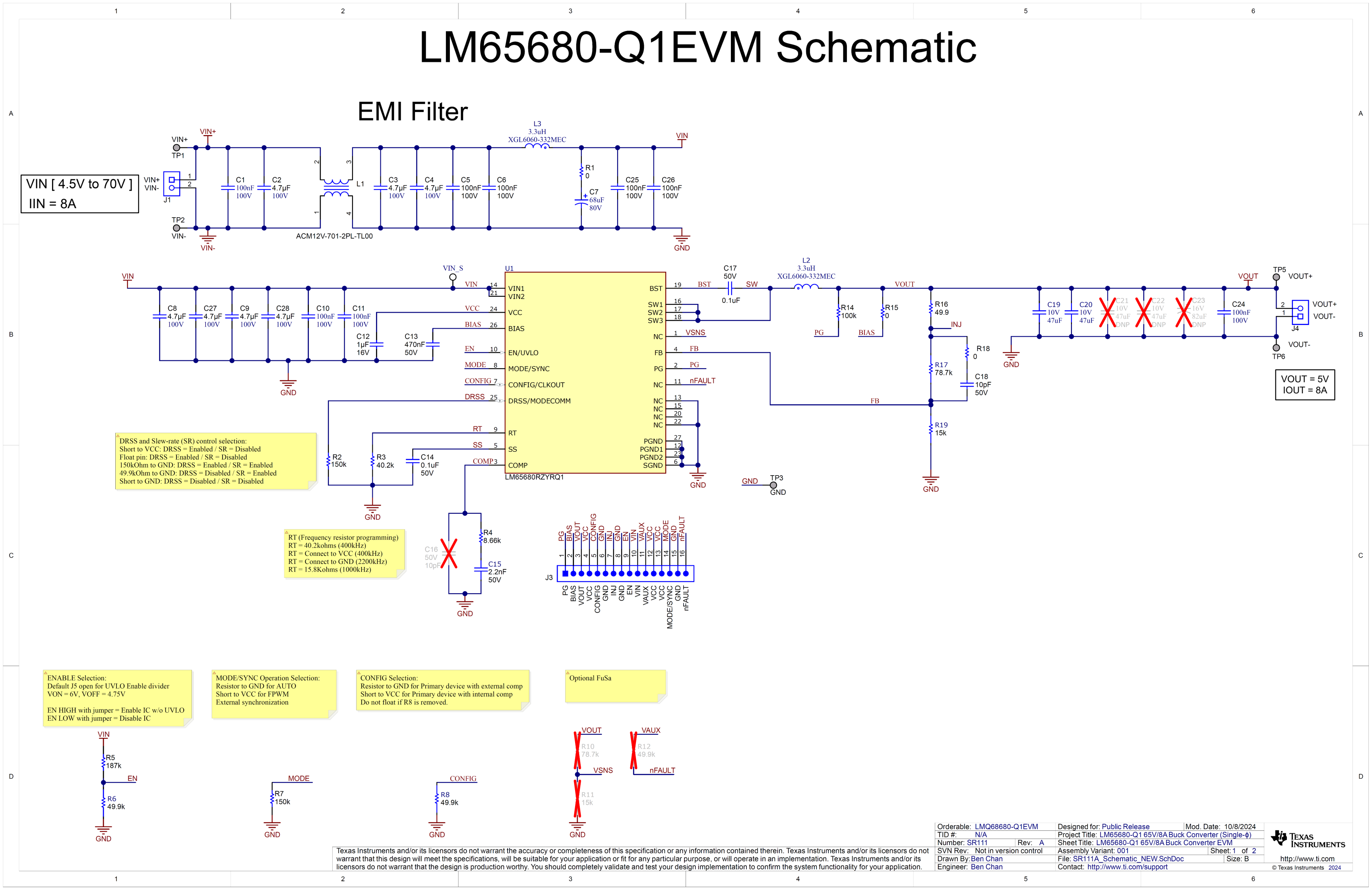


Figure 4-1. EVM Schematic

4.2 PCB Layout

The design of the LM65680-Q1 EVM using a four-layer 62mils standard thickness PCB with 2oz. copper on all layers is shown in Figure 4-2 through Figure 4-9.

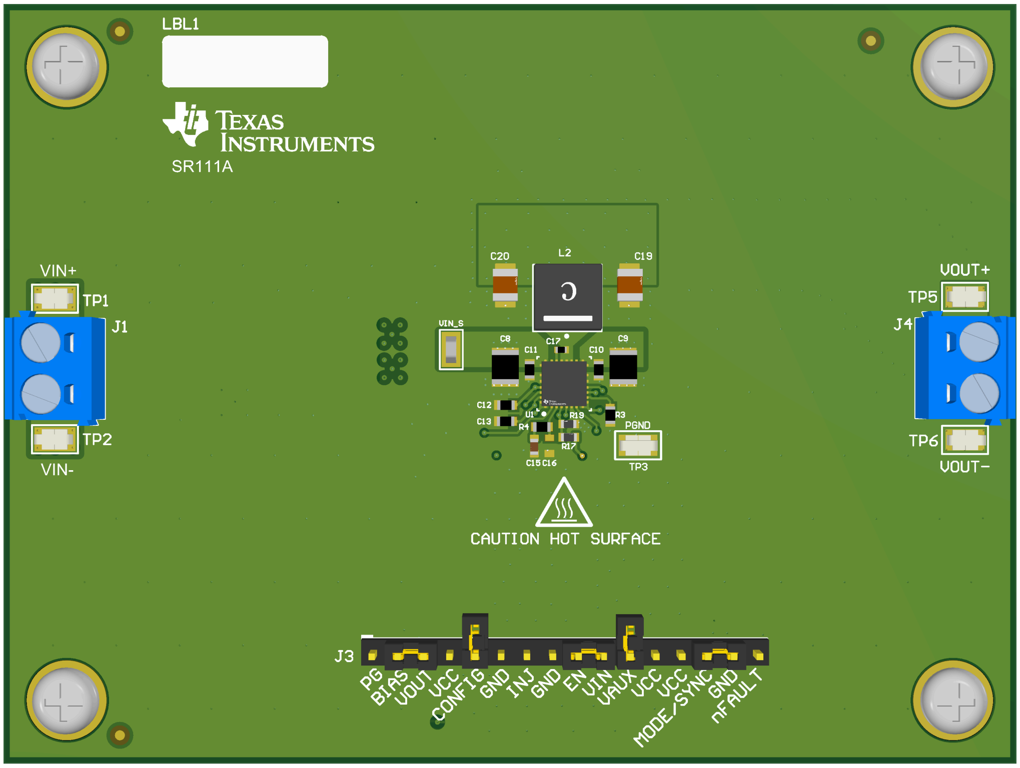


Figure 4-2. Top 3D View

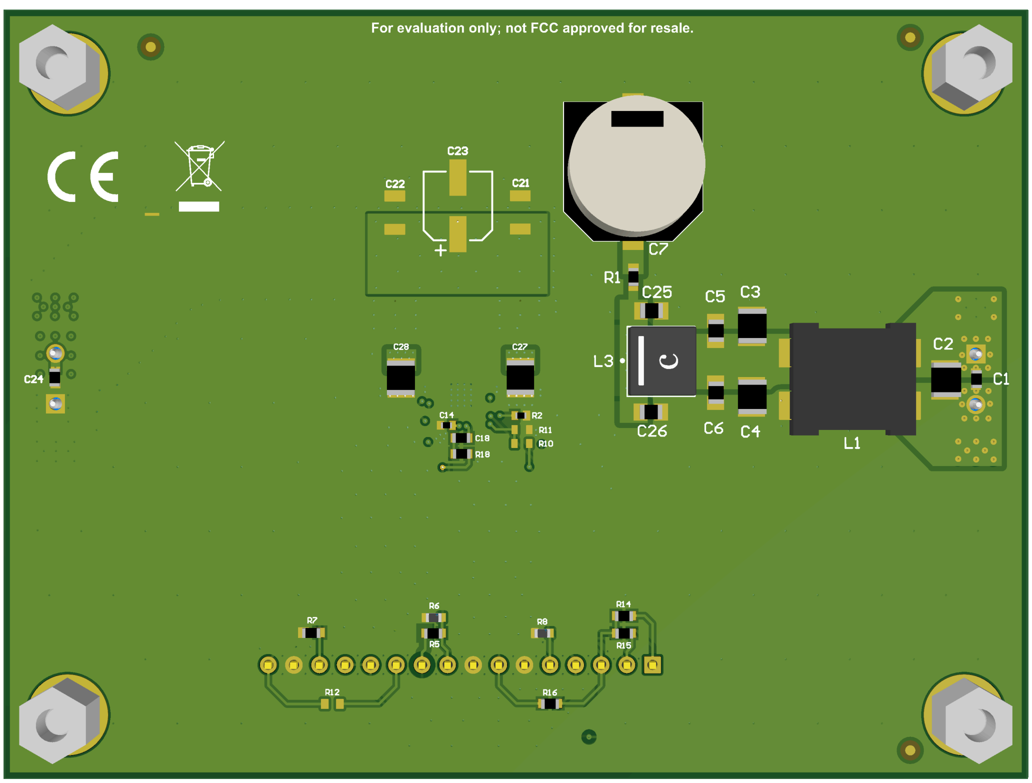


Figure 4-3. Bottom 3D View (viewed from Bottom)

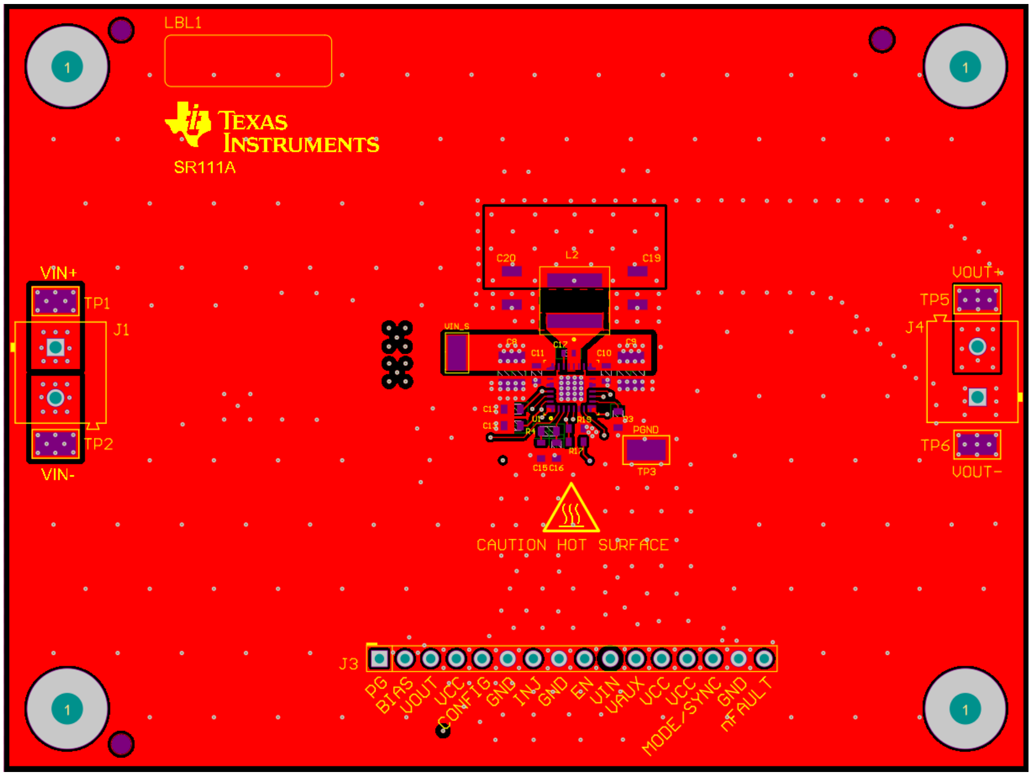


Figure 4-4. Top Layer Copper (Top View)

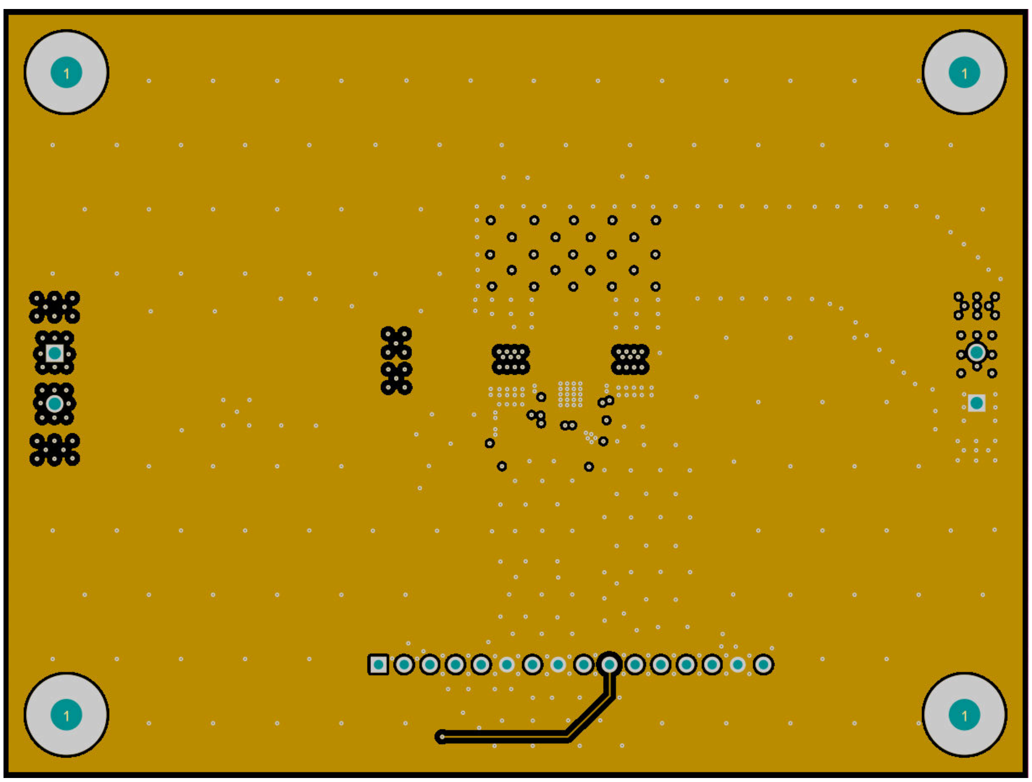


Figure 4-5. Layer 2 Copper (Top View)

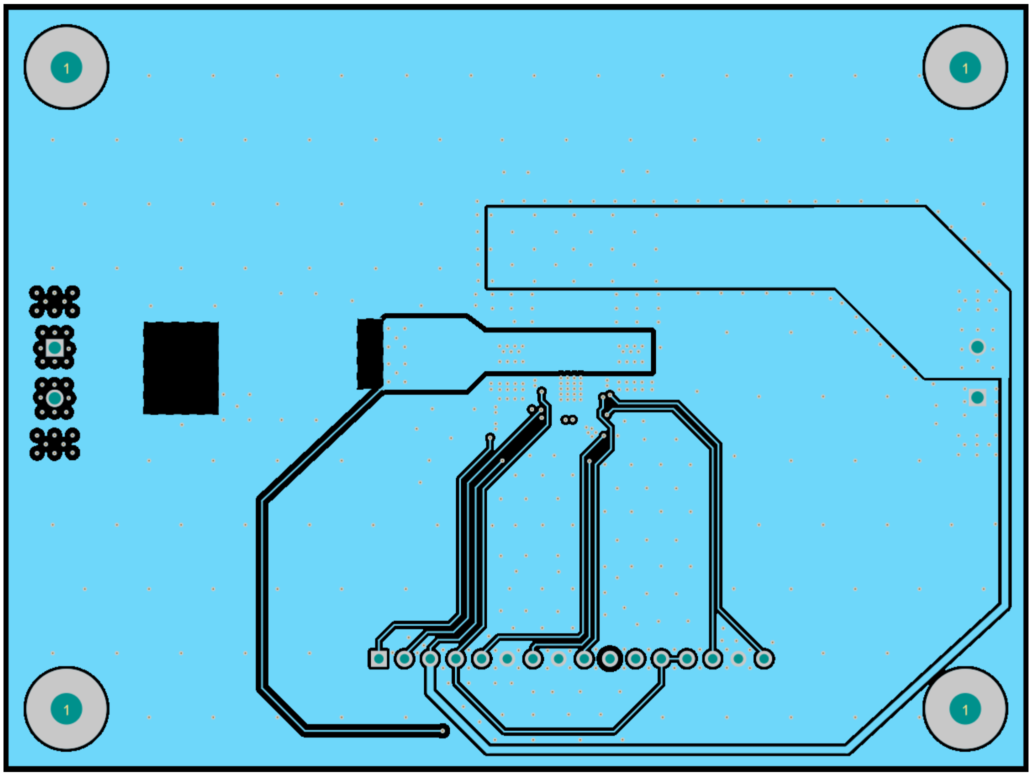


Figure 4-6. Layer 3 Copper (Top View)

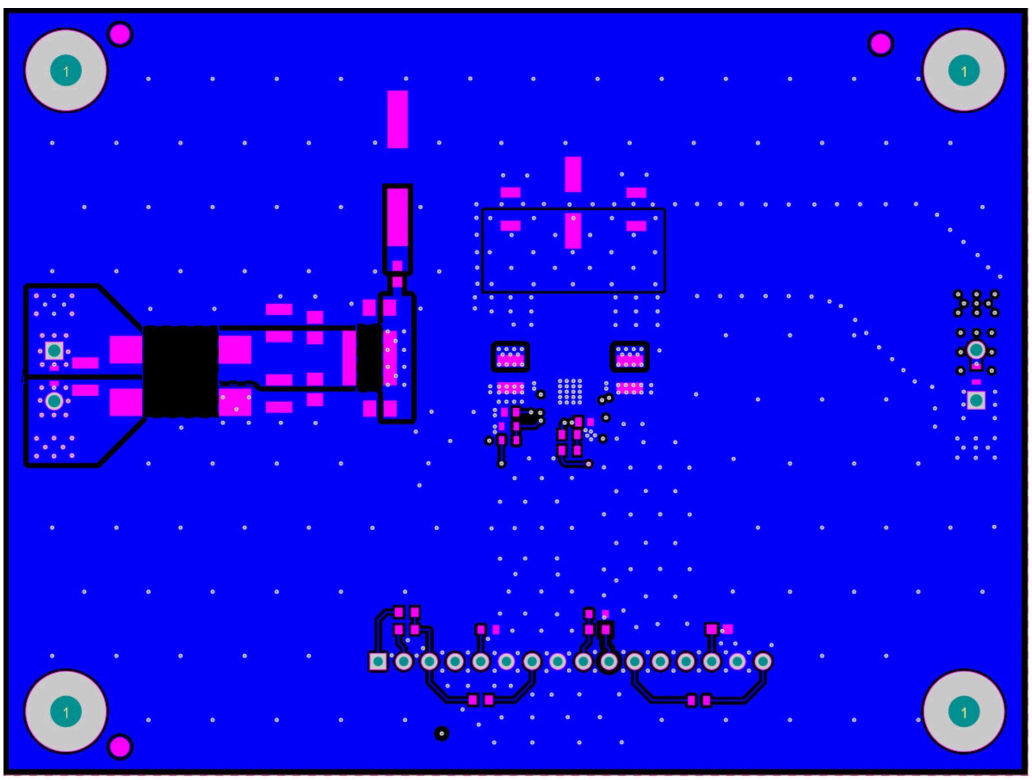


Figure 4-7. Bottom Layer Copper (Inverted)

4.2.1 Component Drawings

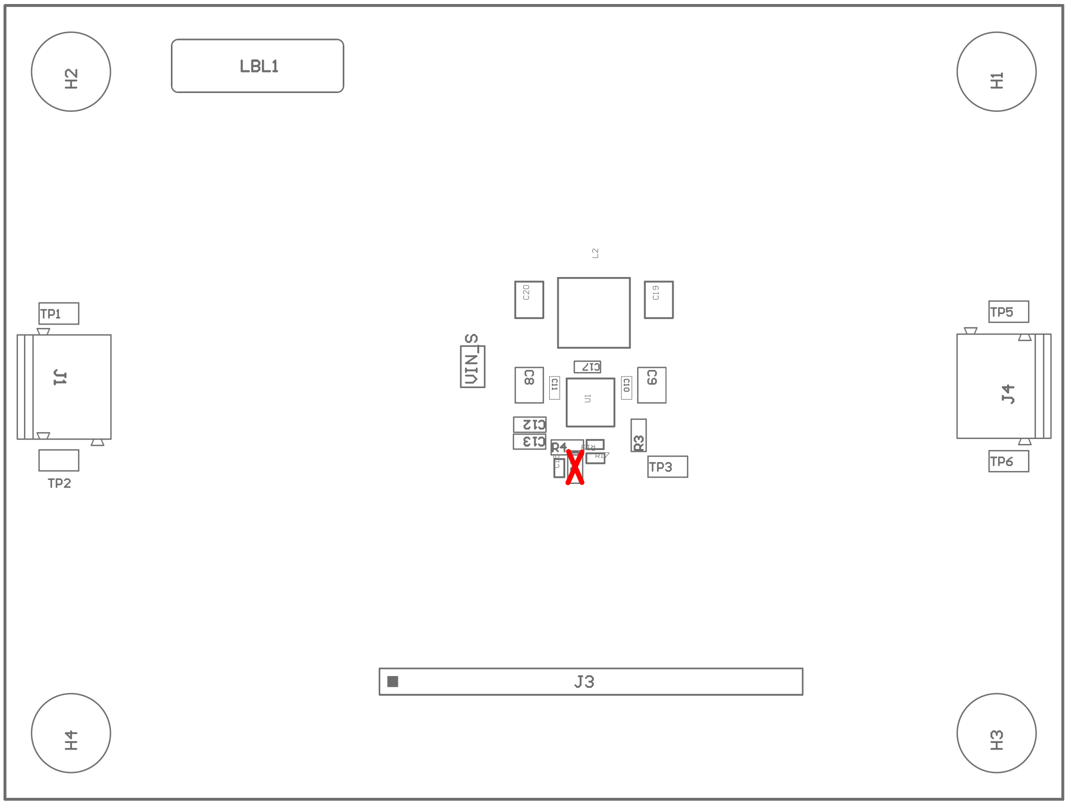


Figure 4-8. Top Component Drawing

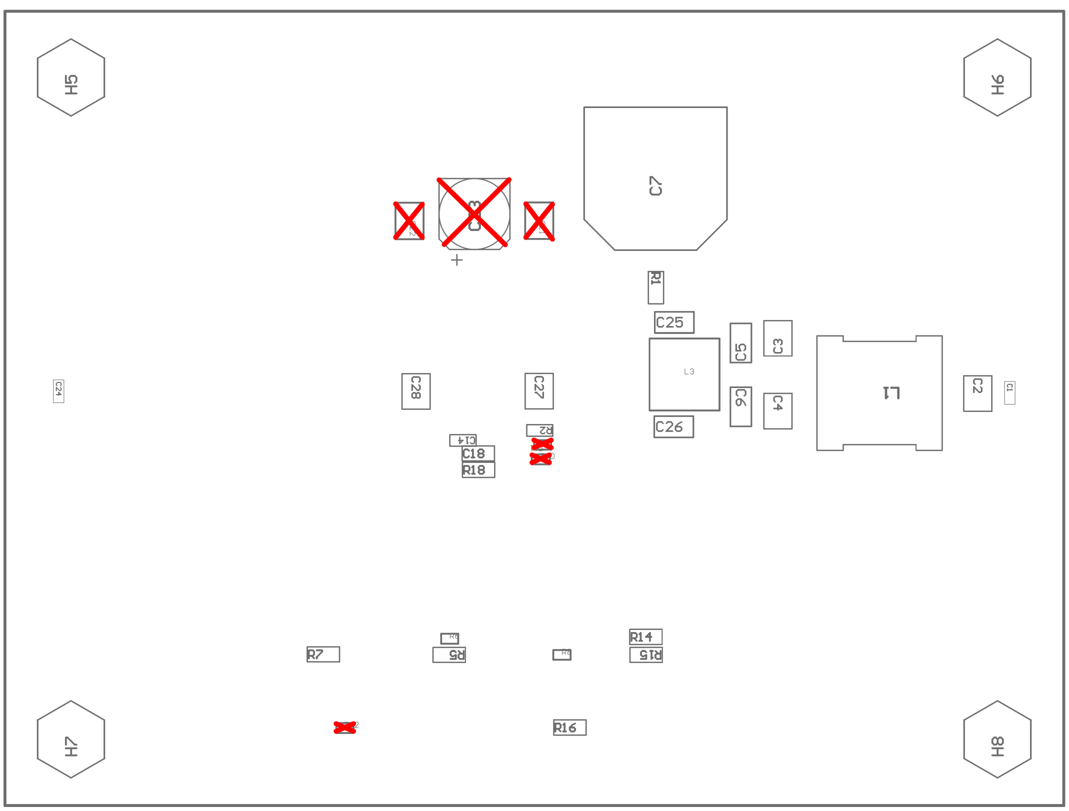


Figure 4-9. Bottom Component Drawing

4.2.2 Multi-Layer Stackup

#	Name	Material	Type	Weight	Thickness	Dk	Df
	Top Overlay		Overlay				
	Top Solder	Solder Resist	Solder Mask		0.4mil	3.5	
1	Top Layer		Signal	2oz	2.8mil		
	Dielectric1	FR-4 High Tg	Core		5mil	4.2	
2	Signal Layer 1		Signal	2oz	2.8mil		
	Dielectric 2	FR-4 High Tg	Prepreg		40mil	4.2	
3	Signal Layer 2		Signal	2oz	2.8mil		
	Dielectric 3	FR-4 High Tg	Core		5mil	4.2	
4	Bottom Layer		Signal	2oz	2.8mil		
	Bottom Solder	Solder Resist	Solder Mask		0.4mil	3.5	
	Bottom Overlay		Overlay				

Figure 4-10. Layer Stackup

4.3 Bill of Materials

Table 4-1. Component BOM

REF DES	QTY	VALUE	DESCRIPTION	PACKAGE	PART NUMBER	MANUFACTURER
C1, C10, C11, C24	4	0.1µF	CAP, CERM, 0.1µF, 100V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	0603	GCJ188R72A104KA01D	MuRata
C2, C3, C4, C8, C9, C27, C28	7	4.7µF	CAP, CERM, 4.7µF, 100V, +/- 10%, X7S, AEC-Q200 Grade 1, 1210	1210	GCM32DC72A475KE02L	MuRata
C5, C6, C25, C26	4	0.1µF	CAP, CERM, 0.1µF, 100V, +/- 10%, X7R, AEC-Q200 Grade 1, 0805	0805	CGA4J2X7R2A104K125AA	TDK
C7	1	68µF	CAP, AL, 68µF, 80V, +/- 20%, 0.32ohm, AEC-Q200 Grade 2, SMD	SMT Radial H13	EEV-FK1K680Q	Panasonic
C12	1	1µF	CAP, CERM, 1µF, 16V, +/- 20%, X7R, AEC-Q200 Grade 1, 0603	0603	GCM188R71C105MA64D	MuRata
C13	1	0.47µF	CAP, CERM, 0.47µF, 50V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	0603	CGA3E3X7R1H474K080AB	TDK
C14, C17	2	0.1µF	CAP, CERM, 0.1µF, 50V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	0402	CGA2B3X7R1H104K050BB	TDK
C15	1	2.2nF	Ceramic Capacitor Automotive 2200pF ±10% 50V X7R 0603	0603	UMJ107AB7222KAHT	Taiyo Yuden
C18	1	10pF	CAP, CERM, 10pF, 50V, +/- 5%, C0G/NP0, 0603	0603	CGA3E2C0G1H100D080AA	TDK
C19, C20	2	47µF	Ceramic Capacitor for Automotive 47µF ±10% 10VDC X7S 1210 Embossed T/R	1210	GCM32EC71A476KE02K	Murata
H1, H2, H3, H4	4		Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply
H5, H6, H7, H8	4		Standoff, Hex, 0.5"L #4-40 Nylon	Standoff	1902C	Keystone
J1, J4	2		Terminal Block, 5mm, 2x1, Tin, TH	Terminal Block, 5mm, 2x1, TH	691 101 710 002	Wurth Elektronik
J3	1		Header, 100mil, 16x1, Gold, TH	16x1 Header	TSW-116-07-G-S	Samtec
L1	1		Coupled inductor, 7.6µH, 700ohm, AEC-Q200 Grade 1, SMD	12x11mm	ACM12V-701-2PL-TL00	TDK
L2, L3	2	3.3µH	Shielded Power Inductors 3.3uH 20% tol, 6.5mOhm 16.6A	SMT_6MM51_6M M71	XGL6060-332MEC	Coilcraft
R1, R15, R18	3	0	RES, 0, 1%, 0.1W, AEC-Q200 Grade 0, 0603	0603	RMCF0603ZT0R00	Stackpole Electronics Inc
R2	1	150k	RES, 150k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	0402	CRCW0402150KFKED	Vishay-Dale
R3	1	40.2k	RES, 40.2k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	0603	CRCW060340K2FKEA	Vishay-Dale
R4	1	8.66k	RES, 8.66k, 1%, 0.1W, 0603	0603	RC0603FR-078K66L	Yageo
R5	1	187k	RES, 187k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	0603	CRCW0603187KFKEA	Vishay-Dale
R6, R8	2	49.9k	49.9kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	0603	CRCW060349K9FKEA	Vishay
R7	1	150k	RES, 150k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	0603	CRCW0603150KFKEA	Vishay-Dale

Table 4-1. Component BOM (continued)

REF DES	QTY	VALUE	DESCRIPTION	PACKAGE	PART NUMBER	MANUFACTURER
R14	1	100k	RES, 100k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	0603	CRCW0603100KFKEA	Vishay-Dale
R16	1	49.9k	RES, 49.9, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	0603	CRCW060349R9FKEA	Vishay-Dale
R17	1	78.7k	78.7kOhms ±0.5% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	0603	ERJ-3RBD7872V	Panasonic
R19	1	15k	15kOhms ±0.1% 0.15W Chip Resistor 0603 (1608 Metric) Anti-Sulfur, Automotive AEC-Q200 Thin Film	0603	RQ73C1J15KBTD	TE Connectivity
SH-J1, SH-J2, SH-J3, SH-J4, SH-J5	5	1x2	Shunt, 100mil, Gold plated, Black	Shunt	SNT-100-BK-G	Samtec
TP1, TP2, TP3, TP5, TP6	5		Test Point, Miniature, SMT	Test Point, Miniature, SMT	5019	Keystone
VIN_S	1		Testpoint_Keystone_Miniature	Test Point, Miniature, SMT	5015	Keystone
U1	1		70V, 8A Automotive Buck Converters Optimized for Low EMI and High Power Density	VQFN-FCRLF26	LM65680RZYRQ1	Texas Instruments
C16	0	10pF	CAP, CERM, 10pF, 50V, +/- 5%, C0G/NP0, 0603	0603	GRM1885C1H100JA01D	Murata
C21, C22	0	47µF	Ceramic Capacitor for Automotive 47µF ±10% 10VDC X7S 1210 Embossed T/R	1210	GCM32EC71A476KE02K	Murata
C23	0	82µF	CAP, Aluminum Polymer, 82µF, 16V, +/- 20%, 0.03ohm	1210	875105344009	Wurth Elektronik
R10	0	78.7k	78.7kOhms ±0.5% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	0603	ERJ-3RBD7872V	Panasonic
R11	0	15k	15kOhms ±0.1% 0.15W Chip Resistor 0603 (1608 Metric) Anti-Sulfur, Automotive AEC-Q200 Thin Film	0603	RQ73C1J15KBTD	TE Connectivity
R12	0	49.9k	49.9kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Automotive AEC-Q200 Thick Film	0603	CRCW060349K9FKEA	Vishay

5 Compliance Information

5.1 Compliance and Certifications

LM65680-Q1EVM EU Declaration of Conformity (DoC) for Restricting the use of Hazardous Substances (RoHS)

6 Related Documentation

For related documentation, see the following:

- Texas Instruments, *LM65680-Q1 70V, 8A, Automotive Buck Converter Optimized for Low EMI and High Power Density* data sheet
- Texas Instruments, *Reduce Buck Converter EMI and Voltage Stress by Minimizing Inductive Parasitics* analog applications journal
- Texas Instruments, *AN-2162 Simple Success with Conducted EMI from DC-DC Converters* application report
- White papers:
  - Texas Instruments, *Valuing Wide V_{IN}, Low EMI Synchronous Buck Circuits for Cost-driven, Demanding Applications*
  - Texas Instruments, *An Overview of Conducted EMI Specifications for Power Supplies*
  - Texas Instruments, *An Overview of Radiated EMI Specifications for Power Supplies*

6.1 Supplemental Content

6.1.1 Development Support

For development support, see the following:

- For TI's reference design library, visit TI reference designs.
- For TI's WEBENCH Design Environments, visit the WEBENCH® Design Center.
- LM65680-Q1 DC/DC Converter Quickstart Calculator.

6.1.2 PCB Layout Resources

- Texas Instruments, *AN-1149 Layout Guidelines for Switching Power Supplies* application report
- Texas Instruments, *AN-1229 Simple Switcher PCB Layout Guidelines* application report
- Texas Instruments, *Constructing Your Power Supply – Layout Considerations Power Supply Design* seminar
- Texas Instruments, *Low Radiated EMI Layout Made SIMPLE with LM4360x and LM4600x* application report
- Power house blogs:
  - *High-Density PCB Layout of DC-DC Converters*

6.1.3 Thermal Design Resources

- Texas Instruments, *AN-2020 Thermal Design by Insight, Not Hindsight* application report
- Texas Instruments, *AN-1520 A Guide to Board Layout for Best Thermal Resistance for Exposed Pad Packages* application report
- Texas Instruments, *Semiconductor and IC Package Thermal Metrics* application report
- Texas Instruments, *Thermal Design Made Simple with LM43603 and LM43602* application report
- Texas Instruments, *PowerPAD™ Thermally Enhanced Package* application report
- Texas Instruments, *PowerPAD™ Made Easy* application brief
- Texas Instruments, *Using New Thermal Metrics* application report

7 Additional Information

7.1 Trademarks

PowerPAD™ is a trademark of Texas Instruments.
All trademarks are the property of their respective owners.

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM ("Software") shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d’usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

3.3.2 *Notice for Users of EVMs Considered “Radio Frequency Products” in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html

3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

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